(*Paper No. 3098.*)

"Note on the Endurance of Steel Bars subjected to repetitions of Tensional Stress."

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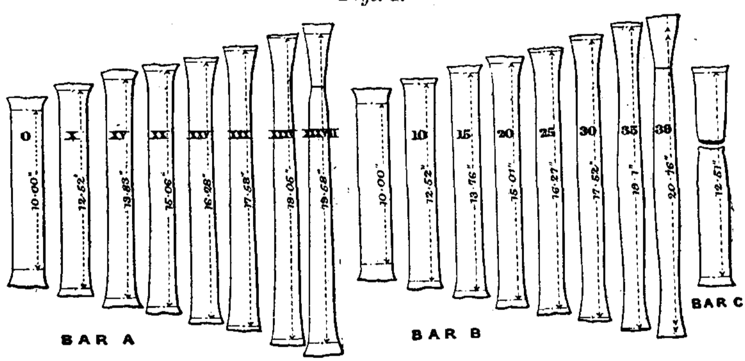
This Paper relates to a series of experiments upon two mild stee bars, which were repeatedly subjected to tensile stress carried beyond the breaking-down point, the amount of extension being kept approximately the same throughout the experiments. The chief points it was desired to determine were:—(1) The total amount of extension to be obtained under such conditions; (2) whether the tensile stress at breaking-down point was influenced by successive stretchings and annealings; and (3) the ratio of the work done on a bar

Figs. 1.



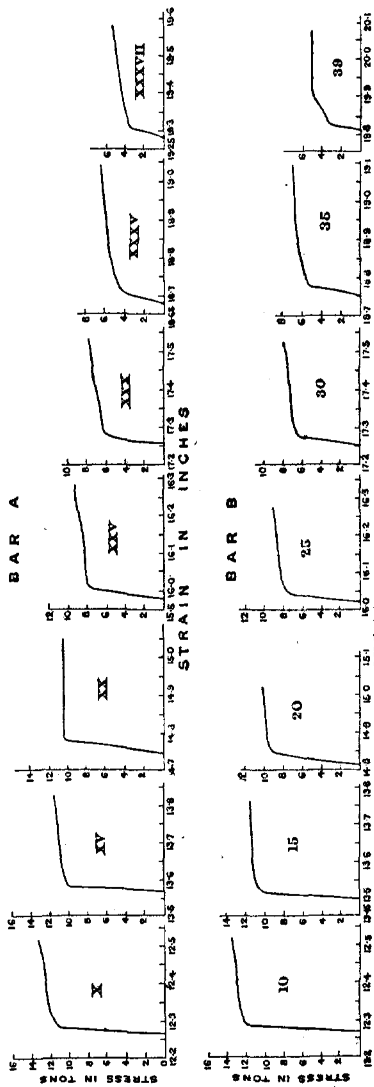
Scale, 1 inch = 1 foot.

broken under ordinary conditions to that done on a similar bar broken under the conditions given.

Three bars of mild steel were cut from the same piece of boiler-plate, and were annealed and machined to size by a special machine in the testing-house. They were 10 inches long, 2 inches broad, and 0·44 inch thick. A chemical analysis showed that the amount of combined carbon in the steel from which the test-pieces were made was 0·16 per cent. Two of the bars, marked A and B respectively, were subjected to tensional stress followed by annealing, and the third bar C was broken in the ordinary manner.

The testing-machine first used was of the Wicksteed type, with a beam to test up to 50 tons, the jockey weight being 1 ton. The testing-machine afterwards used was capable of exerting a pull of 100 tons, and was similar to the smaller one except in details, the most important being that the beam was short and the jockey weight was 2 tons. The extensions of the bars were measured by a Kennedy extensometer of the ordinary type, to measure to 0·001 inch, and, for the rougher measurements, a pair of beam compasses with fine points was used, which, with the aid of a magnifying glass, gave measurements accurate to 0·01 inch.

Figs. 2.

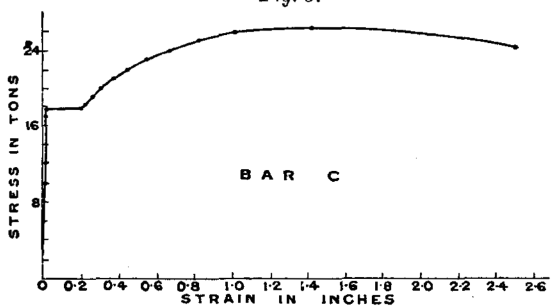


It was found by experiment upon other similar bars that when the breaking-down point was reached, the sudden extension at this point was rather less than 0·25 inch, and it was decided to extend each bar 0·25 inch before annealing and commencing anew. Occasionally an extension of 0·3 inch was reached before the load could be taken off. At the conclusion of each experiment the bar was measured and afterwards annealed by an experienced tool-smith. The annealing was performed by heating the entire test-piece to a dull red heat in an ordinary blacksmith's fire, and allowing it to cool in lime. The percentage of combined carbon being small, there was little danger of burning the plate during heating.

The dimensions of the bars at the conclusion of the tenth, fifteenth, twentieth, twenty-fifth, thirtieth, thirty-fifth and last experiments are shown in *Figs. 1*, together with the corresponding stress-strain diagrams, *Figs. 2*. The figures marked with Roman numerals refer to bar A, and those with ordinary figures refer to bar B.

Extensions of the Bars.—The total extensions of the bars A and B, treated in the manner described, are approximately four times that of the bar C broken in the ordinary manner, *Fig. 3*. The bar A was subjected to thirty-seven extensions before it broke, involving as many annealings; and its length when fractured

Fig. 3.



measured 19·58 inches between the measuring points. The bar B was subjected to thirty-nine extensions before it broke, and its length when fractured was 20·76 inches. The ratio of the extensions of the bars A and B to that of the bar C are as follows:—

$$\frac{\text{Extension of bar A}}{\text{Extension of bar C}} = \frac{9 \cdot 58}{2 \cdot 57} = 3 \cdot 73$$

$$\frac{\text{Extension of bar B}}{\text{Extension of bar C}} = \frac{10 \cdot 76}{2 \cdot 57} = 4 \cdot 18.$$

These results do not differ more than might be expected, having regard to the possible sources of error, such as extending the bar beyond the fixed amount (0·25 inch), uneven setting in the testing-machine, etc.

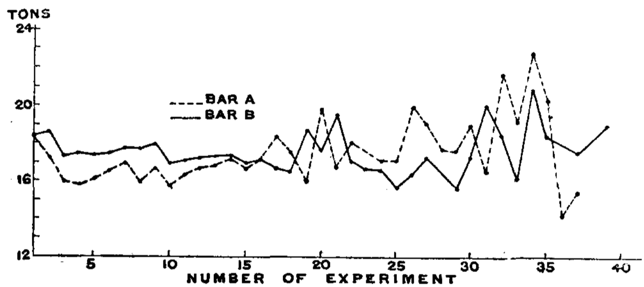
Breaking-Down Point.—The second point which it was sought to determine was whether the stress per square inch at or near the breaking-down point varied with the number of annealings to which the bar was subjected. It was assumed that the bars began to give way at the smallest sections, and on this assumption the results shown in the following Table were obtained:—

Bar A.			Bar B.		
Number of Experiment.	Stress at Breaking Point.	Work Done on Bar.	Number of Experiment.	Stress at Breaking Point.	Work Done on Bar.
	Tons per Square Inch.	Inch-Tons.		Tons per Square Inch.	Inch-Tons.
I	18·18	4·05	1	18·41	4·12
II	17·22	5·04	2	18·62	4·86
III	15·91	3·92	3	17·19	3·50
IV	15·77	3·27	4	17·45	3·71
V	16·03	3·22	5	17·35	3·95
VI	..	4·23	6	..	3·68
VII	16·93	3·62	7	16·00	3·34
VIII	15·93	4·17	8	17·76	4·03
IX	16·71	3·73	9	17·98	3·35
X	15·71	2·99	10	16·92	3·10
XI	16·37	3·38	11	..	3·07
XII	15·69	2·92	12	17·26	3·24
XIII	16·87	3·74	13	17·29	3·48
XIV	17·20	3·34	14	17·33	3·47
XV	16·63	2·70	15	16·91	2·87
XVI	17·09	2·08	16	17·17	2·90
XVII	18·45	2·80	17	16·69	2·94
XVIII	17·51	2·38	18	16·42	2·66
XIX	15·90	2·71	19	18·79	3·40
XX	19·88	2·97	20	17·50	1·72
XXI	16·63	2·17	21	19·60	2·44
XXII	18·10	2·48	22	17·01	2·44
XXIII	23·20	2·10	23	16·59	2·38
XXIV	17·00	2·10	24	16·59	2·56
XXV	17·00	2·44	25	15·67	2·05
XXVI	20·10	2·11	26	16·31	2·52
XXVII	19·07	2·15	27	17·31	1·93
XXVIII	17·66	2·27	28	12·10	1·86
XXIX	17·59	1·75	29	15·62	2·16
XXX	19·04	1·83	30	17·25	1·85
XXXI	16·50	1·54	31	20·17	2·18
XXXII	21·83	1·88	32	18·42	2·92
XXXIII	19·11	1·89	33	16·02	2·50
XXXIV	22·79	2·64	34	20·97	1·39
XXXV	20·38	1·96	35	18·37	1·98
XXXVI	14·10	1·39	36	..	1·48
XXXVII	15·54	1·22	37	17·47	0·96
			38	..	1·66
	Total . .	101·18	39	18·92	1·22
				Total . .	105·82

The successive breaking-down points of the bars A and B were plotted at regular intervals on a vertical scale of 2 tons to the inch.

The broken line on *Fig. 4* represents the results obtained for bar A, while the corresponding full line is for bar B. It will be seen that the curves drop sharply at the commencement, from a value somewhat above 18 tons to a value oscillating about a mean of 17 tons, and up to the end of the sixteenth experiment this average value is fairly maintained; a rise then commences, reaching a maximum at the end of the twentieth experiment where the mean value is 18·7 tons. The mean curve then falls to the end of the twenty-fifth experiment, the mean value at that point being 16·4 tons. From this point to the end of the thirtieth experiment the mean values oscillate between 16·4 tons

Fig. 4.



and 18 tons and finally rise considerably higher. As the bar lengthens during the process it deviates more and more from its original form, and the extensions become more and more local. This effect adds itself to the change produced by the successive extensions and annealings, and it is difficult to allow for it; but from the results obtained it seems clear that with mild steel of this character the breaking-down point will rise considerably before final rupture takes place. An examination of the bars themselves indicated considerable hardness and brittleness.

Determination of the Work done on a Bar broken under ordinary conditions compared with the Work done on a similar Bar broken under the conditions stated above.—The work done on the bars was derived from the areas of the stress-strain diagrams by the formula.

$$\text{Work in inch-tons} = \frac{\text{area of diagram in square inches}}{x\,y},$$

where x inches $=$ 1 inch of extension on the horizontal scale,
y inches $=$ 1 ton on the vertical scale.

The work done on bars A and B at each operation is given in the Table above, whence :—

The total work done on bar A = 101·18 inch-tons;
" " " B = 105·82 "
" " " C = 201·7 "

and

$$\frac{\text{Work done on bar A}}{\text{Work done on bar C}} = \frac{101 \cdot 8}{201 \cdot 7} = 0 \cdot 505\ ;$$

$$\frac{\text{Work done on bar B}}{\text{Work done on bar C}} = \frac{105 \cdot 82}{201 \cdot 7} = 0 \cdot 524.$$

These results are in fair accord, and show that the work done on each of the bars A and B, when stretched from 10 inches to approximately 20 inches by successive steps of 0·25 inch and annealed after each operation, is about half that done on an exactly similar bar broken in the testing-machine in the ordinary way. It appears, therefore, that with mild steel bars subjected to tensile stress followed by annealing under the conditions described, that :—

(1) The total extension is about four times that of a bar broken in the ordinary manner.

(2) The breaking-down stress is of an approximately uniform value during the first stage when the bar has not deviated much from its original form, followed by a considerable divergence, the general tendency of which is to a considerable rise in value.

(3) The work done on a bar under the given conditions is approximately one-half of that done upon a bar broken under tensile stress in the ordinary manner.

Through the kindness of Mr. F. W. Webb, M. Inst. C.E., the Author was enabled to commence the experiments in the Testing House at Crewe Works; they were afterwards carried on in the Fulton Laboratory, Edinburgh University, under Professor G. F. Armstrong, M. Inst. C.E.

The Paper is accompanied by four tracings, from which the Figures in the text have been prepared.